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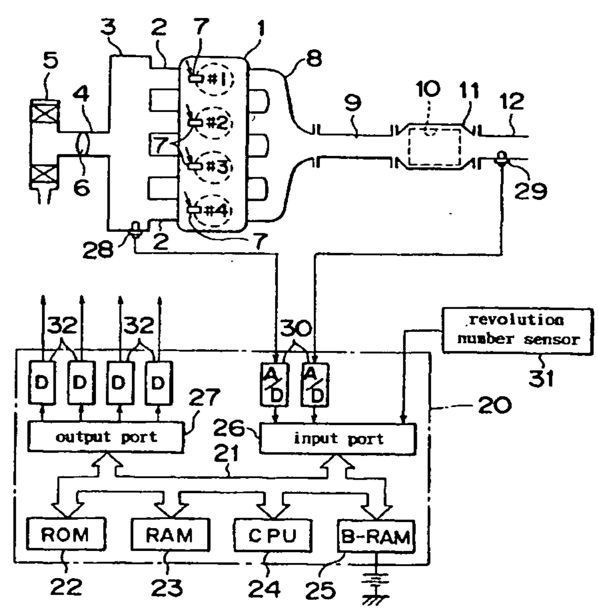
(54) Exhaust discharge control device for internal combustion engine

(57) An NO_X absorbent (10) is arranged in an engine exhaust passage (9) absorbs NO_X when the air-fuel ratio of inflowing exhaust gas is lean and discharges absorbed NO_X or SO_X when the oxygen concentration of inflowing exhaust gas decreases. When the air-fuel ratio of the exhaust gas flowing into the NO_X absorbent (10) is rich, previously absorbed NO_X or SO_X is discharged from the NO_X absorbent. When NO_X or SO_X is to be discharged from the NO_X absorbent (10), oxygen is left in the exhaust gas flowing into the NO_X absorbent (10) and the oxygen concentration of this exhaust gas is maintained within a predetermined range.

FIG. 1



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[0011] This summary of the invention does not necessarily describe all necessary features so that the invention may also reside in a sub-combination of these described features.

BRIEF DESCRIPTION OF THE DRAWING

[0012]

FIG. 1 is an overall view showing an internal combustion engine in a first embodiment according to the present invention;
FIG. 2 shows a map for the basic fuel injection time;
FIGS. 3A and 3B are views for explaining the NO_X absorbing and discharging action of an NO_X absorbent;
FIGS. 4A, 4B and 4C show maps of the coefficient KR;
FIG. 5 is a flow chart showing an NO_X or SO_X discharge control routine;
FIG. 6 is a flow chart for calculating the fuel injection time;
FIGS. 7A, 7B and 7C show maps of a coefficient KLL;
FIG. 8 is a flow chart for calculating the fuel injection time in a second embodiment according to the present invention;
FIG. 9 is an overall view showing an internal combustion engine in a third embodiment according to the present invention;
FIG. 10 is a partially enlarged cross-sectional view of a catalytic converter;
FIG. 11 shows a map of the secondary fuel injection time TN;
FIGS. 12A and 12B are views explaining the NO_X absorbing and discharging action of the NO_X absorbent, the oxygen absorbing and discharging action of an oxygen occluding material and the HC absorbing and releasing action of an HC absorbent;
FIG. 13 shows a map of the secondary fuel injection time TA;
FIG. 14 is a flow chart for the secondary fuel injection control;
FIG. 15 is a timing chart for the fuel sub-injection control in the fourth embodiment according to the present invention;
FIG. 16 is a block diagram showing an essential portion of an exhaust discharge control device in the fifth embodiment according to the present invention;
FIG. 17 is a block diagram showing an essential portion of an exhaust discharge control device in the sixth embodiment according to the present invention in the state where an exhaust directional control valve is located in a back flow position;
FIG. 18 shows an essential portion of the exhaust discharge control device in the sixth embodiment according to the present invention in the state where the exhaust directional control valve is located at the flow position;
FIG. 19 shows an example of the temperature of a catalyst bed at the time of starting SO_X discharge processing in the exhaust discharge control device in the sixth embodiment;
FIG. 20 is a block diagram showing an essential portion of the exhaust discharge control device in the seventh embodiment according to the present invention;
FIG. 21 is a block diagram showing an essential portion of the exhaust discharge control device in the eighth embodiment according to the present invention; and
FIG. 22 is a block diagram showing an essential portion of an exhaust discharge control device in the ninth embodiment according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0013] FIG. 1 shows a first embodiment of the present invention in which the present invention is applied to a spark ignition engine.

[0014] Referring to FIG. 1, an engine main body 1 includes, for example, four cylinders. Each of the cylinders is connected to a surge tank 3 through a corresponding branch pipe 2 and the surge tank 3 is connected to an air cleaner 5 through an intake duct 4. A throttle valve 6 is provided in the intake duct 4. Also, a fuel injection valve 7 is provided in each cylinder for directly injecting fuel into the cylinder. Each cylinder is connected to a catalytic converter 11 provided with an NO_X absorbent 10 through an exhaust gas manifold 8 and an exhaust pipe 9, and the catalytic converter 11 is connected to the exhaust pipe 12.

[0015] An electronic control unit 20 consists of a digital computer and includes an ROM (Read Only Memory) 22, an RAM (Random Access Memory) 23, a CPU (micro processor) 24, a B-RAM (backup RAM) 25 constantly supplied with power, an input port 26 and an output port 27 which are all mutually connected by a two-way bus 21. A pressure sensor 28 generating an output voltage proportional to the internal pressure of the surge tank 3 is provided in the surge tank 3. A temperature sensor 29 generating an output voltage proportional to the temperature of an exhaust gas flowing through the exhaust pipe 12 is provided in the exhaust pipe 12. The pressure sensor 29 may be provided upstream of the catalytic converter 11. The output voltages of the sensors 28 and 29 are inputted to the input port 26 through corresponding AD converters 30, respectively. The CPU 24 calculates an intake air amount Q from the output voltage of the pressure sensor 28. A revolution number sensor 31 generating an output pulse indicating the number of engine revolution is connected to the input port 26. The output port 27 is

[0024] As stated above, the lean gas mixture is normally burned in all of the cylinders within the internal combustion engine. Due to this, the air-fuel ratio of the exhaust gas flowing into the NO_X absorbent 10 is normally lean and NO_X and SO_X within the exhaust gas are, therefore, absorbed by the NO_X absorbent 10. Nevertheless, as the NO_X absorbent 10 has the limited NO_X and SO_X absorbing ability, it is required that NO_X or SO_X is discharged from the NO_X absorbent 10 before the NO_X and SO_X absorbing ability thereof is saturated. In the internal combustion engine shown in FIG. 1, therefore, if the amount of NO_X or SO_X in the NO_X absorbent 10 exceeds a predetermined amount, the air-fuel ratios of the gas mixtures burned in the respective cylinders are temporarily made rich to discharge and reduce NO_X or SO_X from the NO_X absorbent 10. That is, if NO_X or SO_X is discharged from the NO_X absorbent 10, the correction coefficient K(i) is set to K(i) = KR (> 1.0) for all of the cylinders.

[0025] In the above case, it is considered that the good purification of NO_X or SO_X in the NO_X absorbent 10 might not be able to be realized in the presence of oxygen in the NO_X absorbent 10. The inventor of the present invention, however, confirmed that NO_X or SO_X can be well purified in the NO_X absorbent 10 if a certain amount of oxygen exists in the NO_X absorbent 10.

[0026] It has not been clarified why NO_X or SO_X is well purified in the presence of oxygen in the NO_X absorbent 10 while the air-fuel ratio of the exhaust gas flowing into the NO_X absorbent 10 is rich. The reasons might be as follows. Even if the air-fuel ratios of the gas mixtures burned in the respective cylinders are lean in the normal operation, the exhaust gases discharged from the cylinders contain HC. Some of HC is oxidized in the NO_X absorbent 10 and the remaining HC is adhered onto the surface of catalyst particulates, such as platinum Pt particles without being oxidized. Also, if NO_X or SO_X is discharged from the NO_X absorbent 10, the air-fuel ratio of the exhaust gas flowing into the NO_X absorbent 10 is made rich as sated above. Owing to this, a large amount of HC and CO flow into the NO_X absorbent 10 and part of HC and CO are adhered onto the platinum Pt surface. If the air-fuel ratio of the exhaust gas flowing into the NO_X absorbent 10 is lean while HC and CO on the platinum Pt surface increases in amount and cover the surface of platinum Pt, oxygen O_2 cannot be adhered onto the platinum Pt surface in the form of O_2^- or O^{2-}. Owing to this, NO_X is less absorbed by the NO_X absorbent 10, with the result that a large amount of NO_X is discharged from the NO_X absorbent 10. If the air-fuel ratio of the exhaust gas flowing into the NO_X absorbent 10 is rich, NO_X or SO_X, which has been discharged from the NO_X absorbent, on the platinum Pt surface react less with HC and CO in the exhaust gas. As a result, a large amount of NO_X or SO_X is discharged from the NO_X absorbent 10 as well.

[0027] Meanwhile, if oxygen exists in the NO_X absorbent 10 while the air-fuel ratio of the gas mixture burned in each of the cylinders to discharge NO_X or SO_X from the NO_X absorbent 10 is set at a stoichiometric air fuel ratio, oxidization reaction locally occurs around platinum Pt. At this moment, since the temperature of the exhaust gas flowing into the NO_X absorbent 10 is increased in comparison with that in normal operation, the temperature of NO_X absorbent 10 rises accordingly, with the result that HC and CO on the platinum Pt surface are further oxidized with oxygen. HC and CO are, thereby, removed from the platinum Pt surface, ensuring good NO_X or SO_X purification action of the NO_X absorbent 10. Alternatively, if the air-fuel ratios of the gas mixtures burned in the respective cylinders are made rich, HC and CO in the exhaust gas flowing into the NO_X absorbent 10 react with oxygen on the surface of, for example platinum. As a result, the surrounding of the platinum Pt is locally heated to accelerate the reaction of HC and CO adhered onto the platinum Pt surface with oxygen, thereby removing HC and CO from the platinum Pt surface. In either case, if HC is removed from the platinum Pt surface, it is reformed to a reducing agent effective for NO_X or SO_X. This makes it possible to further ensure that NO_X or SO_X discharged from the NO_X absorbent 10 is reduced by the reducing agent.

[0028] However, if the oxygen concentration of the NO_X absorbent 10 is excessively high, HC and CO on the platinum Pt surface or those in the inflowing exhaust gas excessively react with oxygen. As a result, the temperature of the catalytic converter 11 may possibly become excessively high to melt and damage the catalytic converter 11. For that reason, in order to well purify NO_X or SO_X in the NO_X absorbent 10, it is necessary to keep the amount of oxygen within the NO_X absorbent 10 to fall within a predetermined range, i.e., within the range in which HC and CO can be well removed from the platinum Pt surface without melting and damaging the NO_X absorbent 10.

[0029] Taking the above into consideration, in this embodiment, the air-fuel ratio of the gas mixture burned in each of the cylinders, i.e., the coefficient KR is controlled such that the oxygen concentration of the exhaust gas flowing into the NO_X absorbent 10 is kept in the predetermined range when NO_X or SO_X is to be discharged from the NO_X absorbent 10.

[0030] The predetermined range in the spark ignition gasoline engine as in this embodiment ranges from, for example, about 0.3% to about 1.0%. The predetermined range in a diesel engine ranges from, for example, about 1.0% to about 2.0%. The present range for the diesel engine is higher than that for the gasoline engine because the temperature of the exhaust gas in the diesel engine is lower than that in the gasoline engine and the catalytic converter 11 is, thus, less molten and damaged, and also because the fuel of the diesel engine, i.e., light oil, has lower activity than that of gasoline and it requires relatively larger amount of oxygen than gasoline.

[0031] If the temperature of the NO_X absorbent 10 is

the gas mixture burned in the fourth cylinder is set lean. By doing so, the air-fuel ratio of the gas mixture flowing into the NO_X absorbent 10 is made rich and the exhaust gas flowing into the NO_X absorbent 10 contains oxygen at a concentration which falls within the above predetermined range. In this case, the correction coefficients K(1), K(2) and K(3) for the first, second and third cylinders, respectively, are set at a certain coefficient KRR (> 1.0) and the correction coefficient K(4) for the fourth cylinder is set at a coefficient KLL (< 1.0). The coefficient KLL is controlled in accordance with the temperature of the NO_X absorbent 10 and with the amount of HC adhered onto the NO_X absorbent 10. That is, as shown in FIG. 7A, the coefficient KLL is set to be lower as the exhaust gas temperature TEX is higher, whereby the oxygen concentration of the exhaust gas flowing into the NO_X absorbent 10 becomes higher as the increase in the exhaust gas temperature TEX. In addition, as shown in FIG. 7B, the coefficient KLL is set to be lower as the amount SHC of HC adhered is larger, whereby the oxygen concentration of the exhaust gas flowing into the NO_X absorbent becomes high if the amount SHC of adhered HC is high. It is noted that the coefficient KLL is stored in the ROM 22 in advance in the form of the map shown in FIG. 7C.

[0042] FIG. 8 shows a routine for calculating a fuel injection time TAU(i) for each of the cylinders. This routine is executed by interruptions at predetermined time intervals. In this embodiment, as in the preceding embodiment, the NO_X discharge control routine shown in FIG. 5 is executed.

[0043] Referring to FIG. 8, in step 60, a basic fuel injection time TP is calculated from the map of FIG. 2. In the next step 61, the amount SH of HC adhered onto the NO_X 10 is calculated. In step 62, it is determined whether or not a flag is set. If the flag is reset, that is, if NO_X or SO_X should not be discharged from the NO_X absorbent 10, the process goes to the next step 63 where the correction coefficient K(i) for each of the cylinders is set at KL, e.g., 0.6. In step 64, a fuel injection time TAU(i) is calculated ($TAU(i) = TP \times K(i)$).

[0044] If the flag is set, the process goes from step 62 to step 65, where the coefficient KLL is calculated from the map of FIG. 7C. In the next step 66, the correction coefficients K(1), K(2) and K(3) for the first, second and third cylinders, respectively, are set at the coefficient KRR and the correction coefficient K(4) for the fourth cylinder is set at the coefficient KLL. In the next step 64, a fuel injection time TAU(i) is calculated.

[0045] Meanwhile, as already stated above, the following idea is proposed. If the air-fuel ratio of the exhaust gas flowing into the NO_X absorbent 10 is made rich and the inflowing exhaust gas contains oxygen, HC and CO within the inflowing exhaust gas first react with oxygen on the surface of, for example, platinum Pt to locally heat the surrounding of, for example, platinum Pt. Thus, the reaction of HC adhered onto the platinum Pt surface with oxygen is accelerated to remove HC and CO from the platinum Pt surface. Based on this idea, it is possible to well remove HC and CO adhered onto the NO_X absorbent 10 by increasing the oxygen concentration of the inflowing exhaust gas if the concentration of the reducing agent (HC, CO) within the exhaust gas flowing into the NO_X absorbent 10 is high.

[0046] Meanwhile, the concentration of the reducing agent (HC, CO) in the exhaust gas flowing into the NO_X absorbent 10 is proportional to the air-fuel ratio of the inflowing exhaust gas. That is, in the embodiment described with reference to FIGS. 7 and 8, it depends on the coefficient KRR for the cylinder in which the rich gas mixture is burned. Therefore, the coefficient KLL for the cylinder, in which the lean gas mixture is burned, may be set to be lower as the coefficient KRR is higher.

[0047] In addition, even if the air-fuel ratio of the exhaust gas is the same, combustion system, the volume of the cylinder and the like differ, depending on the internal combustion engines, and the concentration of the reducing agent in the exhaust gas discharged from the cylinder, therefore, differs, depending on the internal combustion engines. Considering the difference, it is also possible to obtain the concentration of a reducing agent in the exhaust gas discharged from the cylinder for every internal combustion engine in advance and to set the oxygen concentration of the exhaust gas flowing into the NO_X absorbent 10 in accordance with the concentration of the reducing agent.

[0048] FIG. 9 shows a third embodiment in which the present invention is applied to a diesel engine. Referring to FIG. 9, a depressing sensor 33 generating an output voltage proportional to the depressing degree of an accelerator pedal (not shown), is connected to an input port 26 of an electronic control unit 20 through a corresponding AD converter 30.

[0049] FIG. 10 is a partially enlarged cross-sectional view of the catalytic converter 11. Referring to FIG. 10, the catalytic converter 11 of wall-flow type includes a plurality of cells determined by a cell wall 14 formed of porous material such as ceramic and extending almost parallel to the axis of the exhaust passage. In the converter 11, upstream end opening cells 16u each having an exhaust upstream end 15u opened and an exhaust downstream end 15d closed, and downstream end opening cells 16d each having an exhaust upstream end 15u closed and the exhaust downstream end 15d opened, are arranged alternately. An NO_X absorbent 10 is provided on the inner wall surfaces of the upstream end opening cells 16u, while no NO_X absorbent 10 is arranged on the inner wall surfaces of the downstream end opening cells 16d. Therefore, as indicated by an arrow EG in FIG. 10, the exhaust gas flowing into the catalytic converter 11 first flows into the upper end opening cells 16u, sequentially passes through the NO_X absorbent 10 and the cell wall 14, flows into the downstream end opening cells 16d and then flows out of the catalytic converter 11.

[0050] In the diesel engine, a gas mixture is normally

well purify NO_X or SO_X in the NO_X absorbent 10.

[0057] Ceria (cerium oxide) CeO_2, for instance, may be used as an oxygen occluding material and zeolite or mordenite, for instance, may be used as an HC absorbent and may be used as a carrier. In this embodiment, the NO_X absorbent 10 has a carrier of, for example, zeolite or mordenite, which carries at least one metal selected from the group consisting of alkali metal such as potassium K, sodium Na, lithium Li and cesium Cs, and alkali-earth metal such as barium Ba and calcium Ca, rare earth metal such as lanthanum La and yttrium Y, as well as noble metal such as platinum Pt, palladium Pd, rhodium Rh and iridium Ir and ceria CeO_2.

[0058] In the diesel engine shown in FIG. 9, the HC concentration of the exhaust gas discharged during normal operation is relatively low, so that a sufficient amount of HC cannot be absorbed by the HC absorbent during normal operation. In this embodiment, therefore, secondary fuel injection is conducted during normal operation to thereby supply HC to the HC absorbent.

[0059] During normal operation, however, if the air-fuel ratio of the exhaust gas flowing into the NO_X absorbent 10 is lean and secondary fuel injection is conducted to decrease the oxygen concentration of the exhaust gas flowing into the NO_X absorbent 10, then NO_X or SO_X is discharged from the NO_X absorbent 10. In addition, if HC for the secondary fuel injection is oxidized in the NO_X absorbent 10, the temperature of the HC absorbent increases and HC is released from the HC absorbent. To avoid this, the secondary fuel injection time TAUS at which HC is to be supplied to the HC absorbent is set at an injection time TA at which no NO_X is discharged from the NO_X absorbent 10 and no HC is released from the HC absorbent. The injection time TA is obtained in advance through experiment as a function of the accelerator pedal depressing degree DEP and the engine revolution number N and it is stored in the ROM 22 in advance in the form of the map shown in FIG. 13.

[0060] The secondary fuel injection timing FIT is set at RTD, which is set, for example, between CA of 150° and 180° of the ATDC which is delayed from ADV. If the secondary fuel injection timing is delayed, the HC ratio burned in the combustion chamber or the exhaust passage to that obtained by the secondary fuel injection is lowered, thereby maintaining the temperature of the exhaust gas flowing into the NO_X absorbent 10 low. In addition, since the HC supplied to the HC absorbent is heavy HC (high monocular HC), it is difficult to oxidize in the NO_X absorbent 10. It is, therefore, possible to suppress the temperature rise of the HC absorbent during normal operation and to, thereby, suppress the release of HC from the HC absorbent.

[0061] Conversely, if the secondary fuel injection timing is advanced as in the case of discharging NO_X or SO_X from the NO_X absorbent 10, the HC ratio burned in the combustion chamber or exhaust passage increases. Due to this, the temperature of the exhaust gas flowing into the NO_X absorbent 10 increases to thereby accelerate the release of HC from the HC absorbent. Since the HC supplied to the NO_X absorbent at this time is light HC (low molecular HC), it tends to react in the NO_X absorbent 10. It is, therefore, possible to easily reduce NO_X or SO_X discharged from the NO_X absorbent 10. Besides, if part of HC as a result of the secondary fuel injection is burned in the combustion chamber or the exhaust passage, the oxygen in the exhaust gas discharged from the engine is consumed, making is possible to maintain the oxygen concentration of the exhaust gas flowing into the NO_X absorbent 10 to fall within the predetermined range as in the case of the embodiment described with reference to FIGS. 1 to 8.

[0062] In the meantime, the wall-flow type catalytic converter 11 is employed in this embodiment, as already stated above. If using the converter 11 of this type, all of the exhaust gases flowing into the catalytic converter 11 flow through the HC absorbent. This allows the HC absorbent to absorb HC during normal operation and the oxygen occluding material to store oxygen efficiently.

[0063] FIG. 14 shows the routine for secondary fuel injection control in this embodiment. This routine is executed by interruptions at predetermined crank angles. It is noted that the NO_X discharge control routine shown in FIG. 5 is also executed in this embodiment.

[0064] Now referring to FIG. 14, it is first determined whether or not a flag is set in step 70. If the flag is reset, i.e., NO_X or SO_X should not be discharged from the NO_X absorbent 10, the process goes to the next step 71 where TA is calculated from the map of FIG. 13. In step 72, the secondary fuel injection time TAUS is set at TA. In step 73, the secondary fuel injection timing FIT is set at RTD. On the other hand, if the flag is set, i.e., NO_X or SO_X should be discharged from the NO_X absorbent 10, then the process goes from step 70 to step 74 where TN is calculated from the map of FIG. 11. In step 75, the secondary fuel injection time TAUS is set at TN. In step 76, the secondary fuel injection timing FIT is set at ADV.

[0065] It is possible to provide an electric heater at the NO_X absorbent 10 so that the electric heater can heat both the NO_X absorbent 10 and the HC absorbent when the air-fuel ratio of the exhaust gas flowing into the NO_X absorbent 10 is rich. It is also possible to make the air-fuel ratio of the exhaust gas flowing into the NO_X absorbent 10 rich to discharge NO_X or SO_X from the NO_X absorbent 10 since the temperature of the NO_X absorbent 10 increases during engine accelerating operation or immediately thereafter.

[0066] Next, description will be given to an embodiment in which SO_X absorbed is efficiently released or reduced in the occluding and reducing type NO_X catalyst or the SO_X absorber.

[0067] The fuel of the internal combustion engine contains sulfur. If the fuel is burned in the internal combustion engine, the sulfur contained in the fuel is burned to generate sulfur oxide (SO_X). The occluding and reduc-

[0078] In view of the above, at a predetermined timing before the SO_X poisoning of the NO_X catalyst 10 does not worsen(, i.e., before the NO_X purification efficiency deteriorates and the NO_X discharge amount increases), SO_X is discharged from the NO_X catalyst 10 in the catalytic converter 11. Here, the predetermined timing, at which SO_X discharge processing is carried out, can be set at the timing at which the operation time of the engine 1, which is integrated by the ECU 20, reaches the predetermined time or at which the SO_X absorption amount, which is estimated from the history of the operating state of the engine 1, reaches the predetermined amount.

[0079] SO_X needs to be released when the catalysis temperature is high. To ensure high catalysis temperature, the EPU 20 may control SO_X release processing such that the processing is executed at a timing of the acceleration operation or high load operation of the engine 1. Alternatively, the ECU 20 may control the operating state of the engine 1 so as to positively increase exhaust gas temperature during SO_X discharge processing. In either case, the ECU 20 executes SO_X discharge processing while the catalysis temperature of the NO_X catalyst 10 falls within the range suited for SO_X discharge processing.

[0080] In case of executing SO_X discharge processing, the ECU 20 controls the fuel injection valve 7 to execute both main injection and sub-injection, as well as the opening timing and opening period of the fuel injection valve 7 for sub-injection, sub-injection frequency and the like.

[0081] As already described, the SO_X discharge processing needs to be conducted while the catalysis temperature is higher than that in the NO_X discharge processing. If the sub-injection of the fuel is conducted in the same manner as NO_X discharge processing under the temperature conditions, oxygen contained in the exhaust gas is consumed while the exhaust gas flows in the upstream region of the catalytic converter 11 and no oxygen exists in the downstream region of the catalytic converter 11. Due to this, the downstream region cannot be kept under an SO_X dischargeable atmosphere.

[0082] To avoid this, the fuel injection amount for conducting sub-injection once in SO_X discharge processing is set larger than that in NO_X discharge processing to provide the richer air-fuel ratio of the exhaust gas than in NO_X discharge processing. At the same time, as shown in FIG. 15, sub-injection processings are executed intermittently (or in a spike manner) to provide an atmosphere under which the inflowing exhaust gas has a stoichiometric or rich air-fuel ratio as a whole and under which a predetermined amount of oxygen exists at a downstream end of the catalytic converter 11. The atmosphere under which the inflowing exhaust gas has a stoichiometric or rich airflow rate as a whole and a predetermined amount of oxygen exists, is referred to as 'total rich atmosphere' hereinafter.

[0083] The ECU 20 then determines a fuel amount for sub-injection and an oxygen amount to be supplied during SO_X discharge processing based on the catalyst bed temperature which is substituted by the exhaust gas temperature detected by the exhaust temperature sensor 29 as well as the oxygen concentration and reducing agent concentration of the exhaust gas discharged from the engine 1, so as to provide the total rich atmosphere up to the downstream end of the catalytic converter 11.

[0084] As for the intermittent sub-injection method to provide the total rich atmosphere up to the downstream end of the catalytic converter 11, there are proposed a method for setting a sub-injection execution period X shorter than a sub-injection pause period Y and supplying a reducing agent in a spike manner into an exhaust gas having a lean air-fuel ratio, and a method for setting a sub-injection execution period X longer than a sub-injection pause period Y and supplying oxygen in a spike manner into an exhaust gas having a rich air-fuel ratio.

[0085] If the intermittent sub-injection is executed and the total rich atmosphere is provided up to the downstream end of the catalytic converter 11 as described above, it is possible to discharge and reduce SO_X absorbed by all of the NO_X catalysts 10 in the catalytic converter 11 and discharge SO_X as SO_2 to the air. It is noted that NO_X absorbed by the NO_X catalysts 10 is discharged and reduced, and then discharged as N_2 at a time of executing SO_X discharge processing.

[0086] Even if intermittent sub-injection is executed for discharging SO_X as stated above, there is a possibility that oxygen is consumed while the exhaust gas flows in the upstream region of the catalytic converter 11 if the temperature of the NO_X catalyst 10 in the upstream region of the catalytic converter 11 is too high. To avoid this, SO_X discharge processing may be executed when the temperature of the front end portion of the catalytic converter 11 decreases (such as, for example, during deceleration or idling operation) to allow ensuring an oxygen existing atmosphere in the downstream region of the catalytic converter 11. When the temperature of the front end portion of the catalytic converter 11 decreases, the temperature of the back end portion thereof increases. Thus, as SO_X starts to be discharged and reduced from the NO_X catalyst 10 at the back end and the temperature of the back end increases, the SO_X discharge and reduction operation spreads to the front end portion of the catalytic converter 11.

[0087] As seen from the above, according to the exhaust discharge control device in this embodiment, it is possible to discharge and reduce the SO_X absorbed by the NO_X catalyst 10 surely and sufficiently. As a result, it is possible for the catalytic converter 10 to sufficiently recover its NO_X absorbing capability.

[0088] In this embodiment, the fuel injection valve 7 and the ECU 20 for sub-injection control constitute regeneration means and rich atmosphere providing

provided to change the direction of the exhaust gas flowing through the catalytic converter 11 by switching a valve element between a fair flow position shown in FIG. 18 and a back flow position shown in FIG. 17. If the valve element is in the fair flow position shown in FIG. 18, the exhaust directional control valve 120 connects the exhaust pipes 9 and 18 and connects the exhaust pipes 12 and 17. At this moment, the exhaust gas flows through the exhaust pipe 9 the exhaust pipe 18 the catalytic converter 11 the exhaust pipe 17 the exhaust pipe 12 in this order and discharged to the air. The direction in which the exhaust gas flows from the inlet 11a of the catalytic converter 11 toward the outlet 11b thereof is referred to as "fair flow" direction hereinafter. If the valve element of the exhaust directional control valve 120 is in the back flow position shown in FIG. 17, the exhaust directional control valve 120 connects the exhaust pipes 9 and 17 and connects the exhaust pipes 12 and 18. At this moment, the exhaust gas flows through the exhaust pipe 9 the exhaust pipe 17 the catalytic converter 11 the exhaust pipe 18 the exhaust pipe 12 in this order and discharged to the air. The direction in which the exhaust gas flows from the outlet 11b of the catalytic converter 11 toward the inlet 11a is referred to as "back flow" direction hereinafter.

[0102] The exhaust directional control valve 120, which is driven by an actuator 121, switches the valve position. The actuator 121 is controlled by an ECU 20. The controlling of the position of the exhaust directional control valve 120 will be described later in more detail.

[0103] An exhaust temperature sensor 29 which outputs an output signal, corresponding to the temperature of an exhaust gas flowing through the catalytic converter 11, to the ECU 20 is provided at the exhaust pipe 18 in the vicinity of the inlet 11a of the catalytic converter 11.

[0104] A reducing agent supply nozzle 124 and an air supply nozzle 125 are provided at the exhaust pipe 17 upstream of the outlet 11b of the catalytic converter 11. The reducing agent supply nozzle 124 injects fuel (light oil) serving as a reducing agent supplied from the reducing agent supply unit 126 into the exhaust gas flowing through the exhaust pipe 17. The air supply nozzle 125 injects secondary air supplied from the air supply unit 127 into the exhaust gas flowing through the exhaust pipe 17. The operation of the reducing agent supply unit 126 and that of the air supply unit 127 are controlled by the ECU 20 to be described in detail.

[0105] In addition, an input signal from the depressing degree sensor 33 and that from revolution number sensor 15 are inputted to the input port of the ECU 20 as in the case of the preceding embodiment shown in FIG. 9.

[0106] Next, the description will be given to the function of an exhaust discharge control device in this embodiment. First, if NO_X in the exhaust gas is absorbed by the NO_X catalyst 10, the EPU 20 controls the actuator 121 such that the valve element of the exhaust directional control valve 120 is kept in the fair flow position shown in FIG. 18 and the flow direction of the exhaust gas in the catalytic converter 11 is the fair flow direction in which the exhaust gas flows from the inlet 11a toward the outlet 11b. If the exhaust gas is flown in the fair flow direction, NO_X absorption starts at the NO_X catalyst 10 at a side closer to the inlet 11a of the catalytic converter 11 and gradually spreads toward the NO_X catalyst 10 at a side closer to the outlet 11b.

[0107] If NO_X discharge processing is executed, the ECU 20 controls the actuator 121 such that the valve element of the exhaust directional control valve 120 is kept in the fair flow position shown in FIG. 18 and that the flow direction of the exhaust gas in the catalytic converter 11 is the same as that in the NO_X absorption processing. The ECU 20 then controls the operation of the reducing agent supply unit 126 such that the air-fuel ratio of the exhaust gas flowing into the catalytic converter 11 satisfies predetermined rich or stoichiometric conditions. During the NO_X discharge processing, fuel is continuously supplied from the reducing agent supply nozzle 124. By causing the exhaust gas having the stoichiometric or rich fuel-air ratio to flow into the catalytic converter 11, NO_X absorbed in the NO_X catalyst 10 is discharged, reduced and then discharged to the air as N_2.

[0108] If SO_X discharge processing is executed, the ECU 20 controls the actuator 121 such that the valve element of the exhaust directional control valve 120 is kept in the back flow position shown in FIG. 17 and that the flow direction of the exhaust gas in the catalytic converter 11 is the direction opposite to that in the NO_X absorption processing (i.e., from the outlet 11b toward the inlet 11a). Besides, the ECU 20 controls the operation of the reducing agent supply unit 126 and that of the air supply unit 127 so as to provide a total rich atmosphere up to the end portion of the inlet 11a side of the catalytic converter 11.

[0109] To provide a total rich atmosphere up to the end portion of the inlet 11a side of the catalytic converter 11, either of the following two control methods may be adopted.

[0110] Fuel is continuously injected from the reducing agent supply nozzle 124, an exhaust gas containing no oxygen at a predetermined rich air-fuel ratio is continuously supplied to the catalytic converter 11 and, at the same time, secondary air is intermittently supplied from the air supply nozzle 125.

[0111] Alternatively, since the exhaust gas of the diesel engine 1 during normal operation is in a lean state where excessive oxygen exits, it is possible to intermittently supply fuel from the reducing agent supply nozzle 124 and to control the reducing agent supply amount so that the exhaust gas can have a predetermined air-fuel ratio richer than that in NO_X discharge processing without supply of the secondary air from the air supply nozzle 125.

[0112] Further, in case of SO_X discharge processing by means of the back flow regeneration method, it is

predetermined rich air-fuel ratio which is richer than that in the NO_X discharge processing without supplying secondary air from the air supply nozzle 125.

[0127] In this embodiment, the reducing agent supply nozzle 124 and the reducing agent supply unit 126 constitutes regeneration means and rich atmosphere providing means, whereas the air supply nozzle 125 and the air supply unit 127 constitute rich atmosphere providing means.

[0128] FIG. 21 shows the constitution of important parts of an exhaust discharge control device in the eight embodiment. The exhaust discharge control device in this embodiment is a modified version of the device in the seventh embodiment. The difference of the eight embodiment from the seventh embodiment will be described hereinafter.

[0129] In an eighth embodiment, exhaust pipes 9 and 18a are connected by an exhaust pipe 19 and an opening/closing valve 116 is provided midway of the exhaust pipe 19. The opening/closing valve 117 is opened/closed by an actuator 118, which is controlled by an ECU 20. A reducing agent supply nozzle 124 and an air supply nozzle 125 are provided at the exhaust pipe 9 upstream of a connection point between the exhaust pipes 9 and 19.

[0130] In this exhaust discharge control device, at a time of absorbing NO_X, the valve element of an exhaust directional control valve 120 is kept in a fair flow position and an opening/closing valve 117 is kept in an open state. This state is the same as that in NO_X absorption processing in the seventh embodiment and the function thereof is also the same.

[0131] At a time of NO_X discharge processing, the valve element of the exhaust directional control valve 120 is switched to the back flow position with the opening/closing valve 117 kept in a closed state. As a result, an exhaust gas turns into a back flow flowing through an S trap 80 after passing the catalytic converter 11. Fuel is injected from the reducing agent supply nozzle 124 into the exhaust gas, whereby the exhaust gas at the air-fuel ratio turned to be stoichiometric or rich flows into the catalytic converter 11 and NO_X absorbed by the NO_X catalyst 10 in the catalytic converter 11 is discharged and reduced. In the eighth embodiment, the reason for carrying out NO_X discharge processing in back flow direction is that the fuel supplied from the reducing agent supply nozzle 124 is consumed at the S trap 80 before reaching the catalytic converter 11 if the exhaust gas flows in the back flow direction.

[0132] Next, at a time of SO_X discharge processing, the opening/closing valve 117 is switched to an open state and the valve element of the exhaust directional control valve 120 is kept in a back flow position as shown in FIG. 21. By doing so, much of the exhaust gas flows from the exhaust pipe 9 to the exhaust pipe 19, to the exhaust pipe 12 through the S trap 80 and discharged to the air. In addition, some of the exhaust gas in small amount flows from the exhaust pipe 9 to the exhaust pipe 17, to the exhaust pipe 18b through the catalytic converter 11 and flows into the S trap 80. The flow rate of the exhaust gas flowing through the catalytic converter 11 is lowered because of the resistance of the catalytic converter 11.

[0133] During the SO_X discharge processing, the ECU 20 controls the operation of the reducing agent supply unit 126 and that of the air supply unit 127 so as to provide a total rich atmosphere up to the end portion of the S trap 80 at the inlet 80a side by the fuel injection from the reducing agent supply nozzle 124.

[0134] As the method for controlling the operation of the reducing agent supply unit 126 and that of the air supply unit 127 for purposes of providing a total rich atmosphere up to the end portion of the S trap 80 at the inlet 80a side is the same as that in the seventh embodiment, the description will not be given herein.

[0135] FIG. 22 is a schematically block diagram of en exhaust discharge control device for an internal combustion engine in a ninth embodiment according to the present invention.

[0136] The internal combustion engine in this embodiment is a lean burn gasoline engine. As is well known, the lean burn gasoline engine can, unlike the diesel engine, operate whether the air-fuel ratio of an exhaust gas in a combustion chamber is lean or rich. In this embodiment, therefore, the total rich atmosphere for an exhaust gas is realized by controlling the air-fuel ratio for combustion for every cylinder.

[0137] First, the constitution of this exhaust discharge control device will be described with reference to FIG. 22. An engine 100 is a serial four-cylinder lean burn gasoline engine (to be simply referred to as an 'engine' hereinafter) and intake air is supplied from intake pipes which are not shown to cylinders 101 to 104, respectively. In the engine 1, fuel injection valves 111, 112, 113 and 114 for injecting fuel in the vicinity of the compression top dead center are provided in the combustion chambers of the cylinders 101 to 104, respectively. The valve opening timing and period for each of the fuel injection valves 111 to 114 are controlled by the ECU 20 in accordance with the operating state of the engine 1.

[0138] The exhaust gas of the first cylinder 101 and that of the fourth cylinder 104 are discharged to the exhaust pipe 131, whereas the exhaust gas of the second cylinder 102 and that of the third cylinder 103 are discharged to the exhaust pipe 132. Catalytic converters 91 and 92 are provided at the exhaust pipes 131 and 132, respectively and an absorbing and reducing type NO_X catalyst (to be referred to as 'NO_X catalyst' hereinafter) 93 is contained in each of the catalytic converters 91 and 92.

[0139] The exhaust gases passing through the catalytic converters 91 and 92 are discharged to the exhaust pipe 133, in which the exhaust gases discharged from the four cylinders 101 to 104 are combined. A catalytic converter 94 is provided at an exhaust pipe 133 and a well-known ternary catalyst 95 is housed in the con-

combustion engine according to claim 3, wherein the means (29) for detecting the temperature of the NO_X absorbent (10, 91, 92) detects a temperature of the exhaust gas downstream of the NO_X absorbent (10, 91, 92) to obtain the temperature of the NO_X absorbent (10, 91, 92).

5. An exhaust discharge control device for an internal combustion engine according to claim 1, wherein the NO_X absorbent (10, 91, 92) includes a hydrocarbon absorbent, the hydrocarbon absorbent absorbing hydrocarbon when a temperature of the hydrocarbon absorbent is below a predetermined temperature and releasing absorbed hydrocarbon when the temperature of the hydrocarbon absorbent is at least the predetermined temperature.

6. An exhaust discharge control device for an internal combustion engine according to claim 1, wherein the NO_X absorbent (10, 91, 92) includes an oxygen occluding material, the oxygen occluding material storing oxygen when the oxygen concentration of inflowing exhaust gas increases and discharging stored oxygen when the oxygen concentration of inflowing exhaust gas decreases.

7. An exhaust discharge control device for an internal combustion engine according to claim 6, wherein the NO_X absorbent (10, 91, 92) includes a hydrocarbon absorbent, the hydrocarbon absorbent absorbing hydrocarbons when a temperature of the hydrocarbon absorbent is below a predetermined temperature and releasing absorbed hydrocarbons when the temperature of the hydrocarbon absorbent is at least the predetermined temperature.

8. An exhaust discharge control device for an internal combustion engine according to claim 1, further comprising:

air-fuel ratio control means (20) for temporarily lowering an air-fuel ratio of the exhaust gas flowing into the NO_X absorbent (10, 91, 92) and to discharge from the NO_X absorbent (10, 91, 92) the one of NO_X and SO_X absorbed therein.

9. An exhaust discharge control device for an internal combustion engine according to claim 8, wherein the engine includes a plurality of cylinders (7,101) and wherein the air-fuel ratio control means (20) increases a fuel injection quantity for a part of the plurality of cylinders (7,101).

10. An exhaust discharge control device for an internal combustion engine according to claim 8, wherein

the air-fuel ratio control means (20) conducts a fuel injection near a compression top dead center of the engine and a secondary injection in one of an engine expansion stroke and an engine exhaust stroke.

11. An exhaust discharge control device for an internal combustion engine having an occluding and reducing type NO_X catalyst (10, 91, 92) disposed in an exhaust passage (9) of the engine, wherein exhaust gas travels through the exhaust passage (9) from upstream to downstream, the occluding and reducing type NO_X catalyst (10, 91, 92) absorbing NO_X in the exhaust gas flowing therein when an air-fuel ratio of inflowing exhaust gas is lean and discharges absorbed NO_X therefrom when the air-fuel ratio of inflowing exhaust gas is one of stoichiometric and rich, said exhaust discharge control device being characterized by comprising

regeneration means (7, 20) for making the air-fuel ratio of inflowing exhaust gas one of stoichiometric and rich when SO_X absorbed by the occluding and reducing type NO_X catalyst (10, 91, 92) during NO_X absorption is discharged from the occluding and reducing type NO_X catalyst (10, 91, 92); and
rich atmosphere providing means (122, 124, 125) for supplying and maintaining a predetermined amount of oxygen in an SO_X absorption region of the occluding and reducing type NO_X catalyst (10, 91, 92) when the regeneration means (7, 20) executes SO_X discharge.

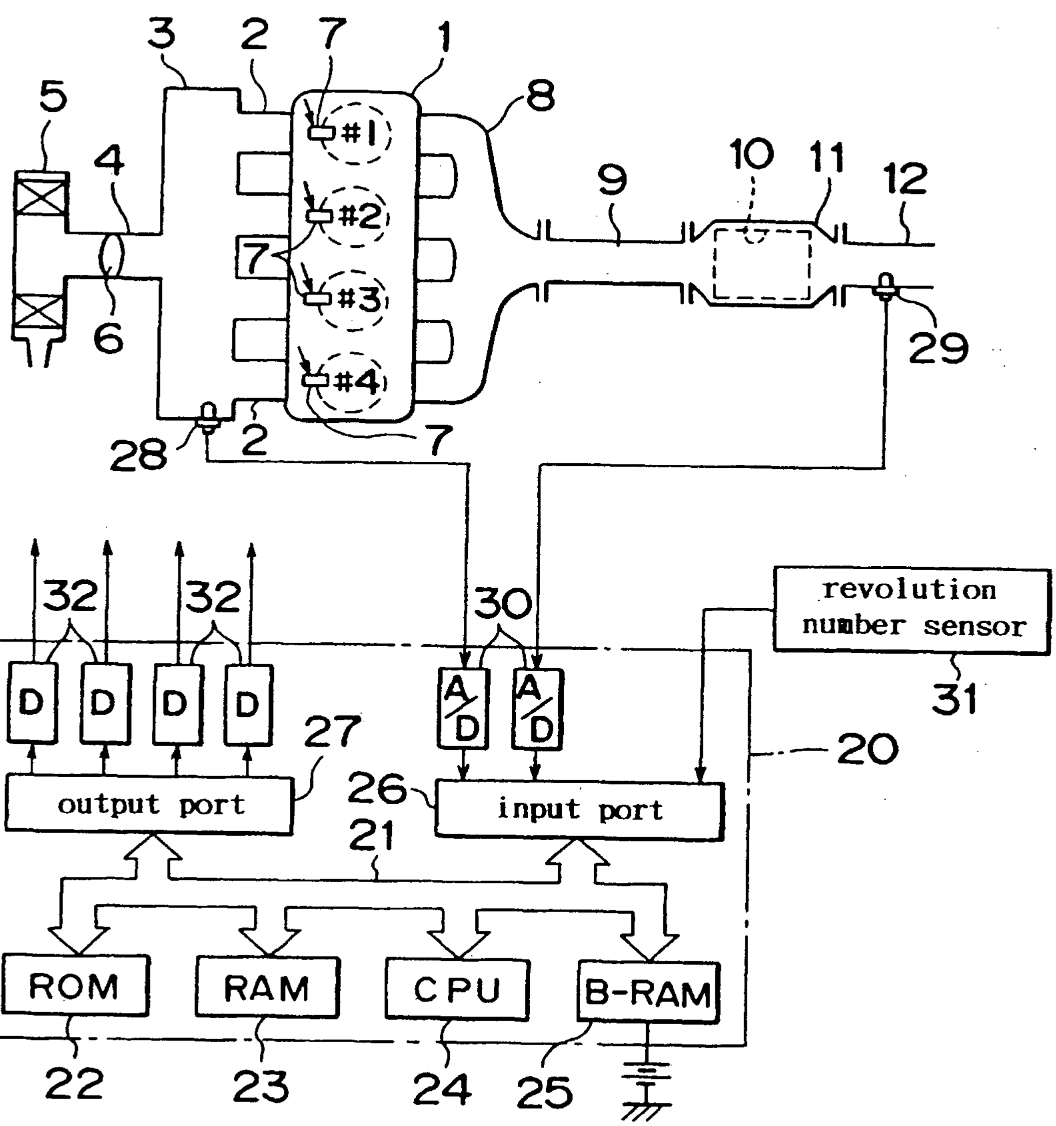
12. An exhaust discharge control device for an internal combustion engine according to claim 11, wherein

a timing of SO_X discharge execution by the regeneration means (7, 20) and the rich atmosphere providing means (122, 124, 125) is controlled at a time at which a catalysis temperature of a downward region of the occluding and reducing type NO_X catalyst (10, 91, 92) in an exhaust gas flow direction during SO_X discharge is higher than a catalysis temperature of an upward region of the occluding and reducing type NO_X catalyst (10, 91, 92).

13. An exhaust discharge control device for an internal combustion engine according to claim 11, wherein said rich atmosphere providing means (122, 124, 125) includes means (41) for supplying oxygen to a catalyst downstream of the occluding and reducing type NO_X catalyst (10, 91, 92) during SO_X discharge.

14. An exhaust discharge control device for an internal combustion engine according to claim 11, wherein said internal combustion engine is a multiple-cylinder internal combustion engine and said rich

FIG. 1



3
2
7
1
5
8
4
#1
9
10
11
12
#2
7
#3
6
29
#4
28
2
7
32
32
30
revolution number sensor
31
D
D
D
D
A/D
A/D
27
20
26
output port
input port
21
ROM
RAM
CPU
B-RAM
22
23
24
25

FIG. 2

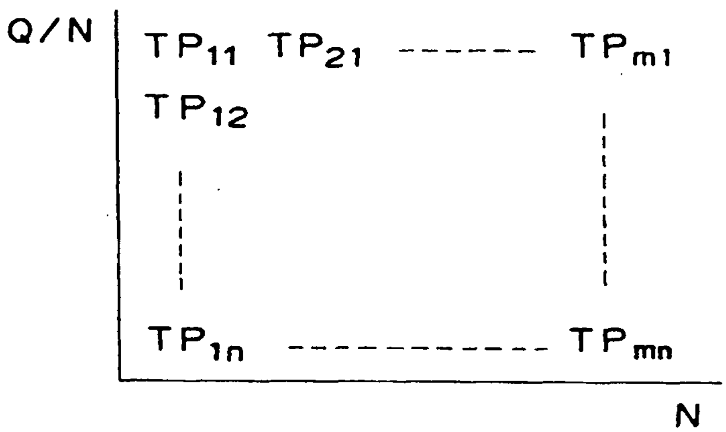


FIG. 3A

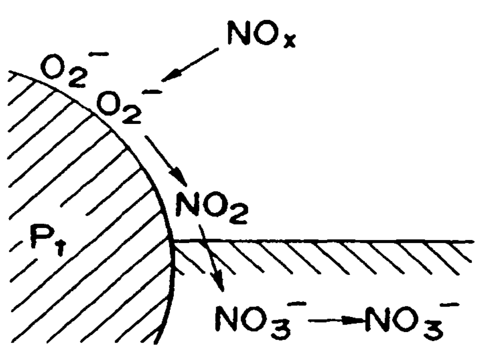


FIG. 3B

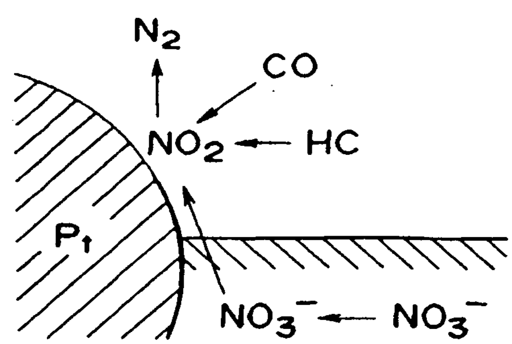


FIG.4A

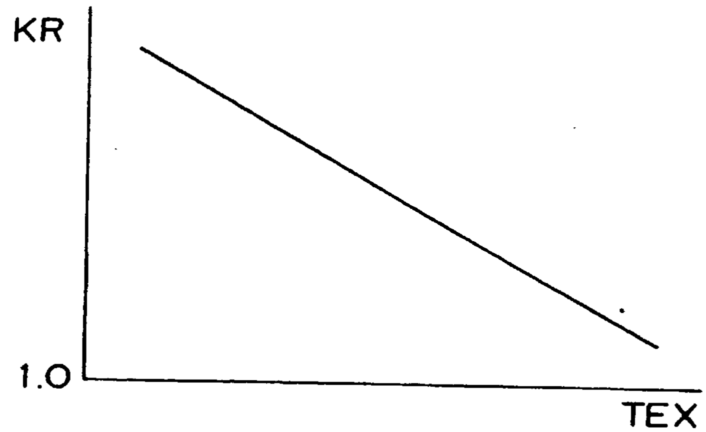


FIG.4B

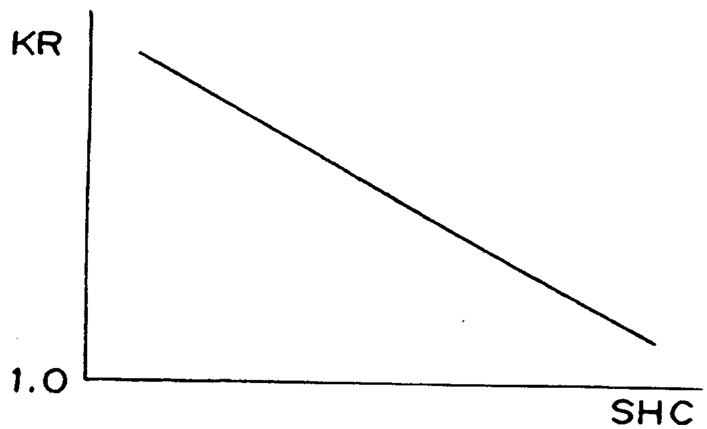


FIG.4C

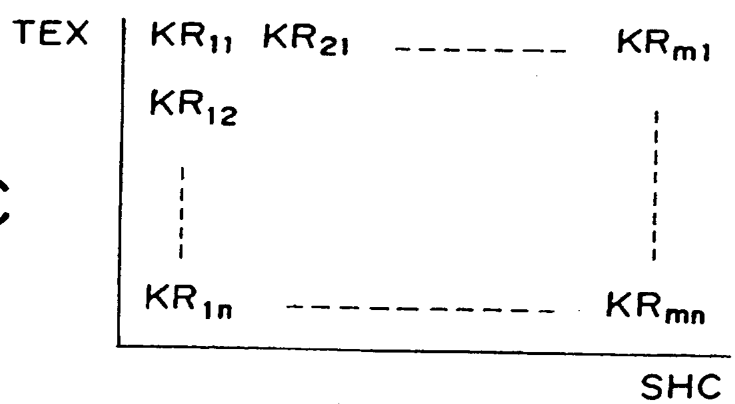


FIG.5

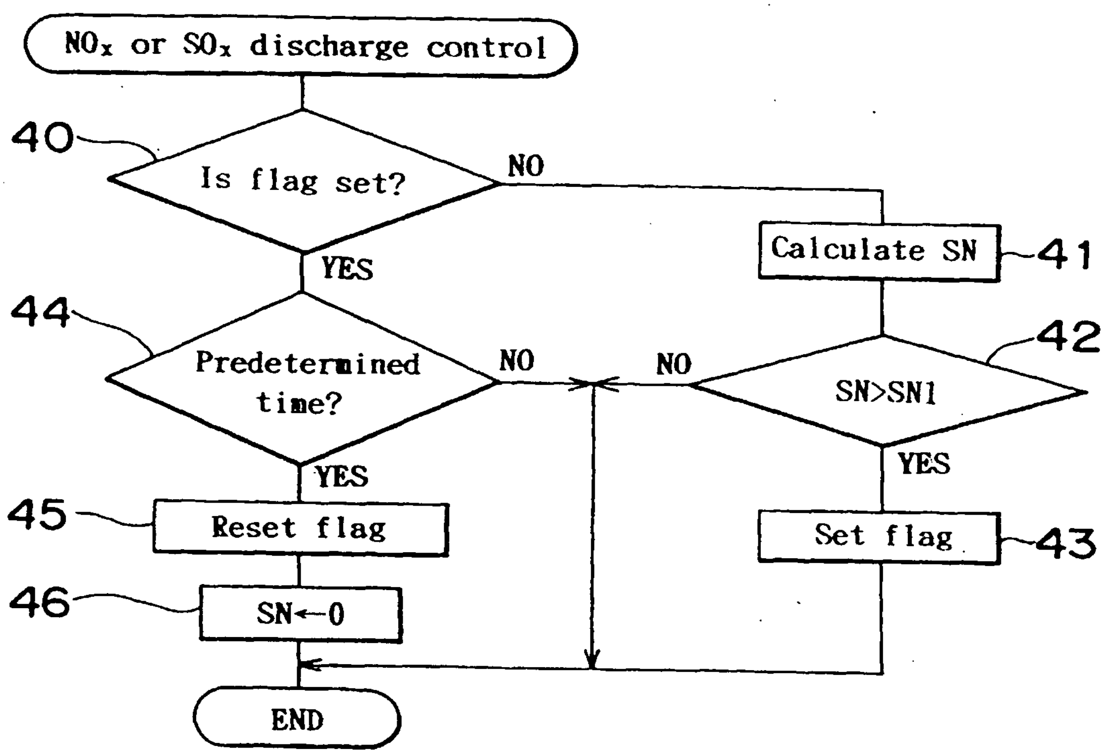

NO_x or SO_x discharge control
40
Is flag set?
NO
YES
Calculate SN
41
44
Predetermined time?
NO
NO
42
SN>SN1
YES
YES
45
Reset flag
Set flag
43
46
SN←0
END

FIG.6

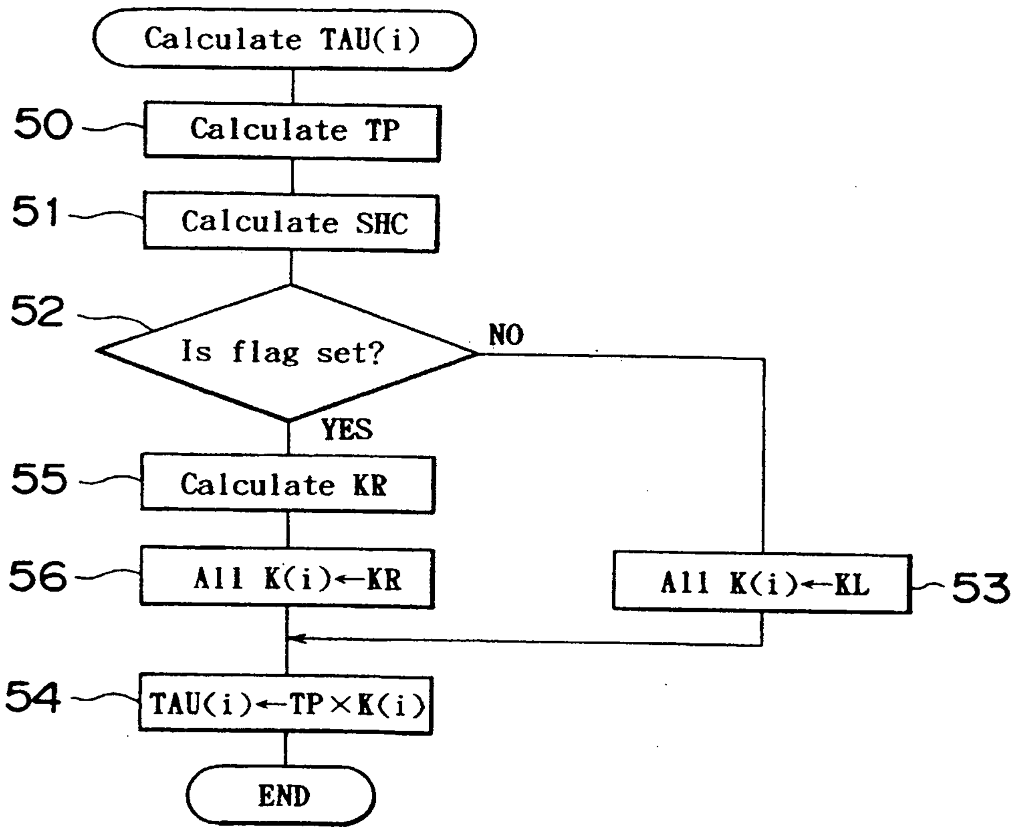

Calculate TAU(i)
50
Calculate TP
51
Calculate SHC
52
Is flag set?
NO
YES
55
Calculate KR
56
All K(i)←KR
All K(i)←KL
53
54
TAU(i)←TP×K(i)
END

FIG.7A

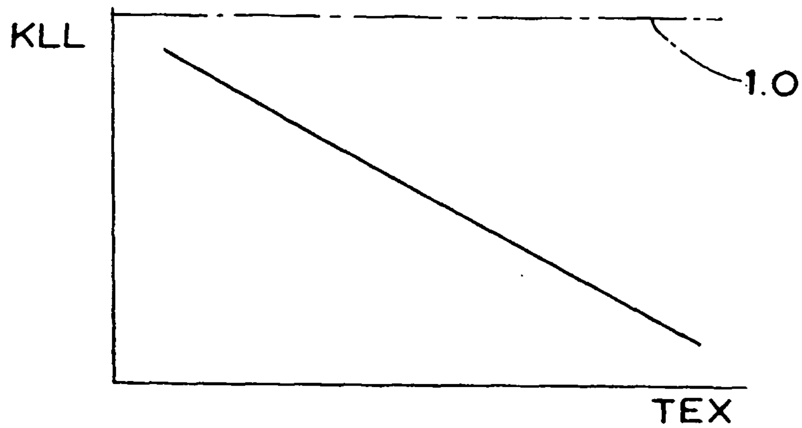


FIG.7B

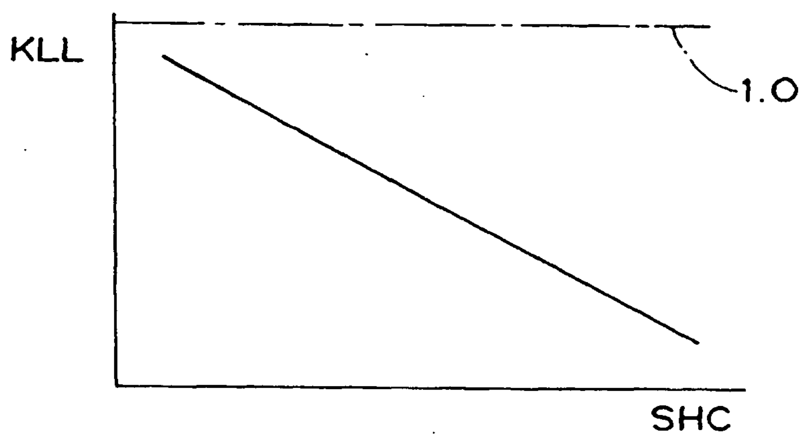


FIG.7C

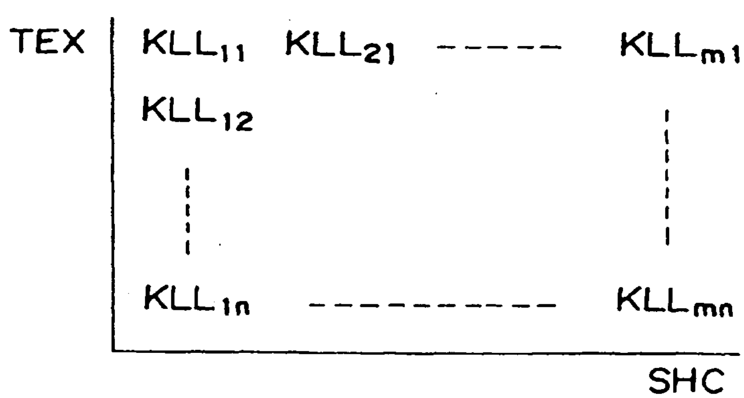


FIG. 8

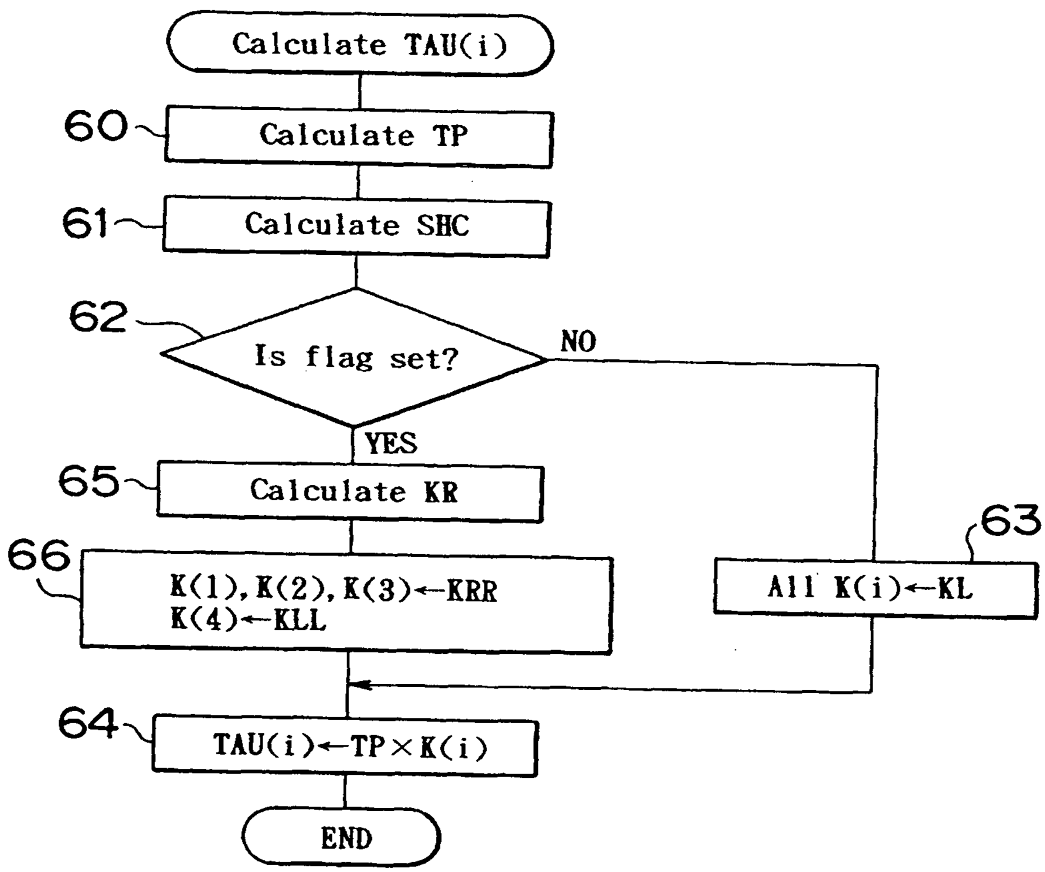

Calculate TAU(i)
60
Calculate TP
61
Calculate SHC
62
Is flag set?
NO
YES
65
Calculate KR
66
K(1), K(2), K(3)←KRR
K(4)←KLL
63
All K(i)←KL
64
TAU(i)←TP×K(i)
END

FIG. 9

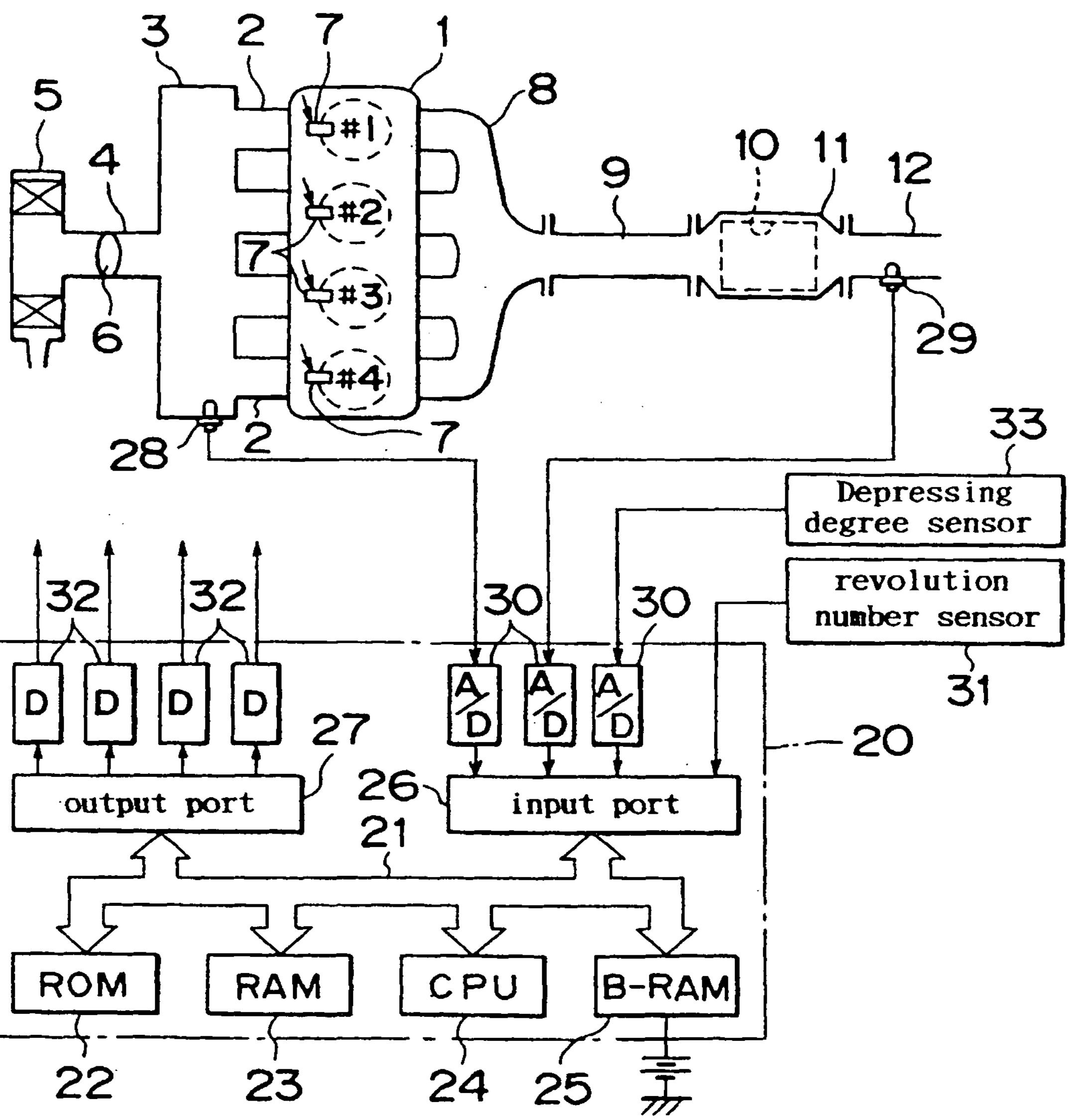

3
2
7
1
5
8
4
10
11
12
9
#1
#2
#3
#4
7
6
29
28
2
7
33
Depressing degree sensor
revolution number sensor
31
32
32
30
30
D
D
D
D
A/D
A/D
A/D
20
27
26
output port
input port
21
ROM
RAM
CPU
B-RAM
22
23
24
25

FIG.10

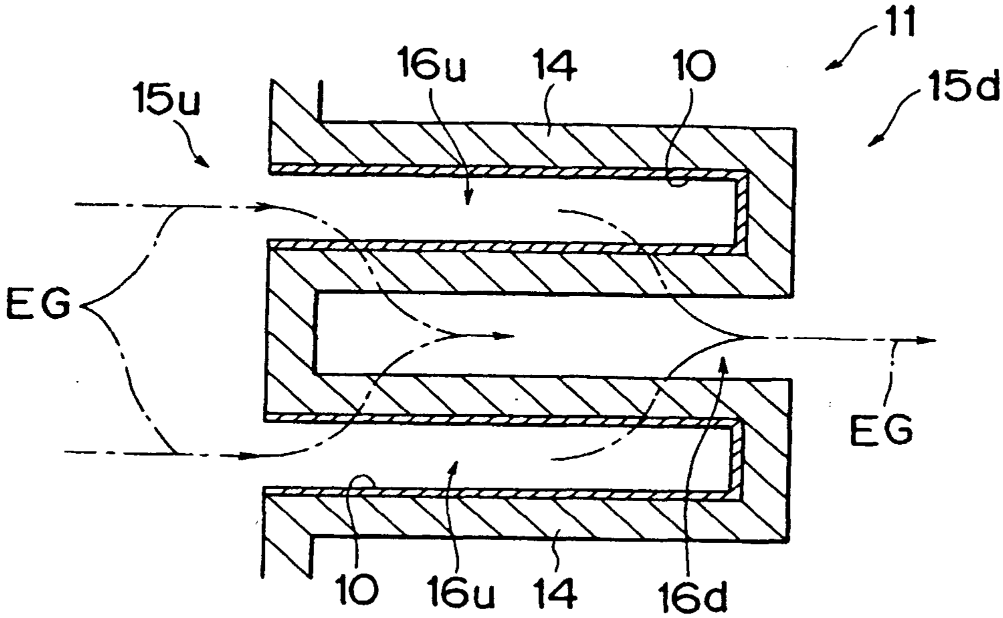

11
15u
16u
14
10
15d
EG
EG
10
16u
14
16d

FIG.11

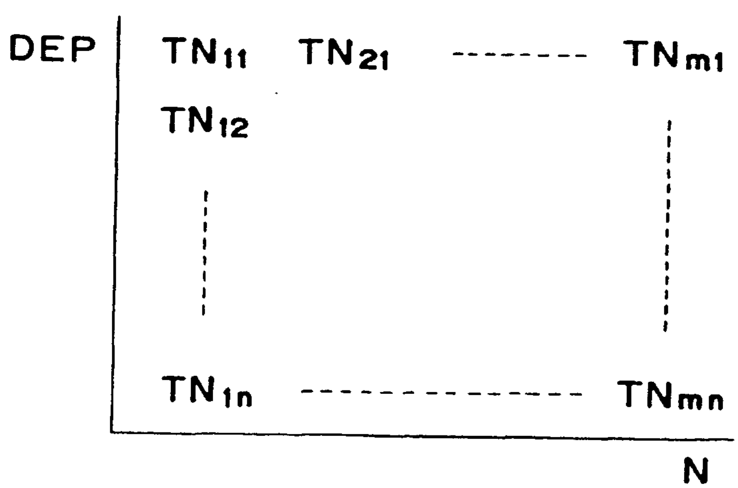

DEP
TN11
TN21
TNm1
TN12
TN1n
TNmn
N

FIG. 12A

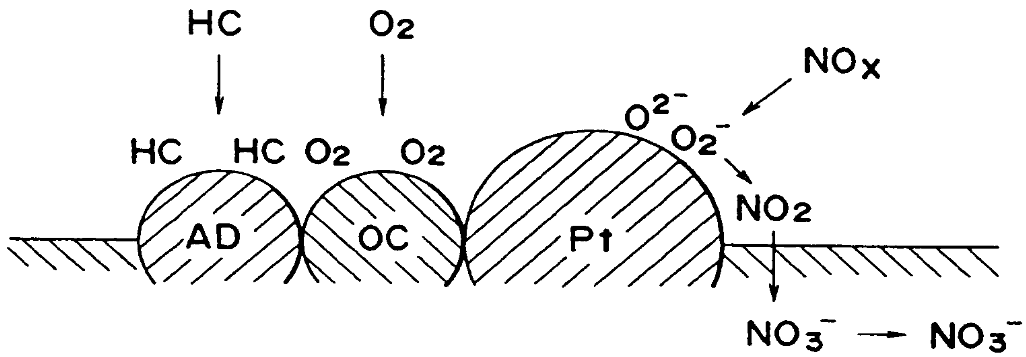


FIG. 12B

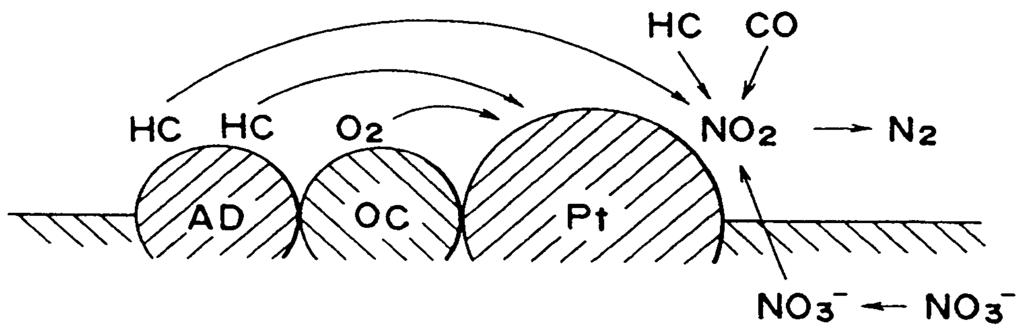


FIG.13

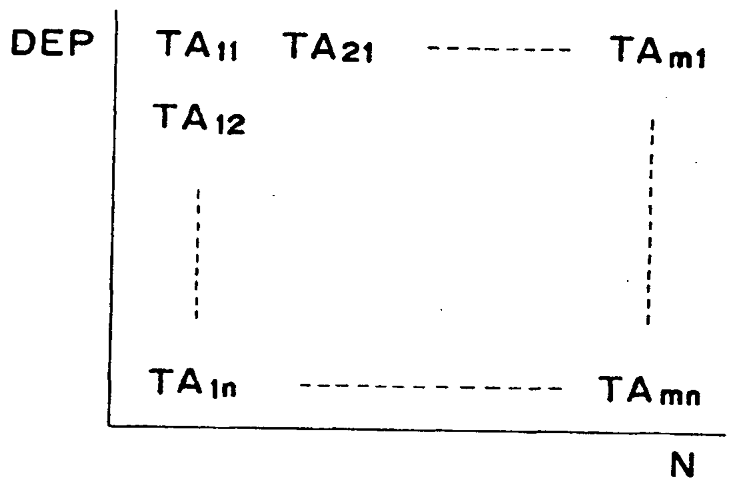

DEP
TA11
TA21
TAm1
TA12
TA1n
TAmn
N

FIG.14

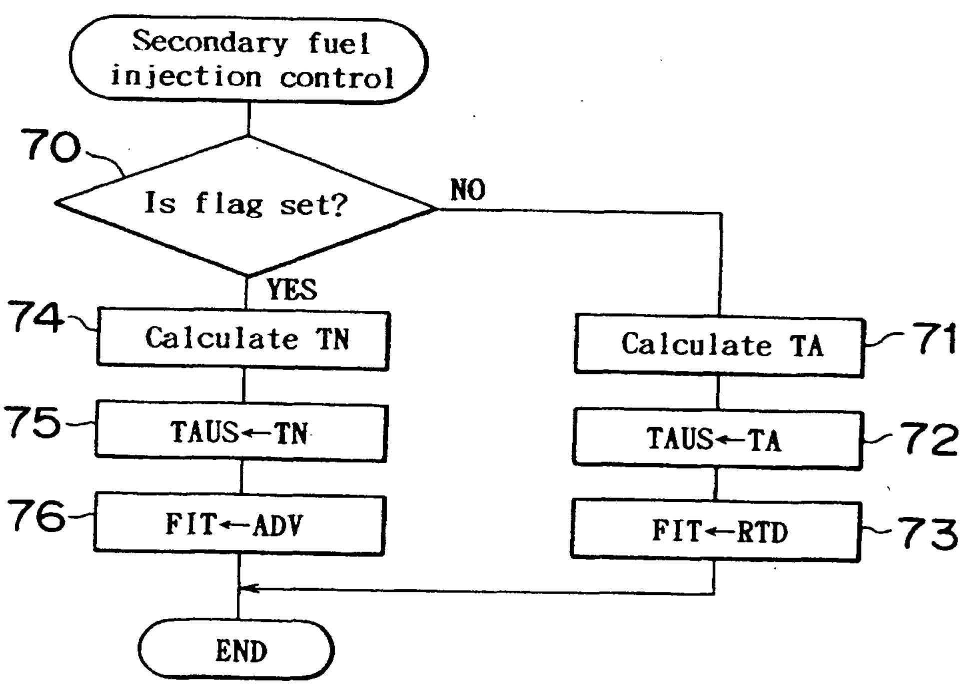

Secondary fuel injection control
70
Is flag set?
NO
YES
74
Calculate TN
75
TAUS←TN
76
FIT←ADV
Calculate TA
71
TAUS←TA
72
FIT←RTD
73
END

FIG.15

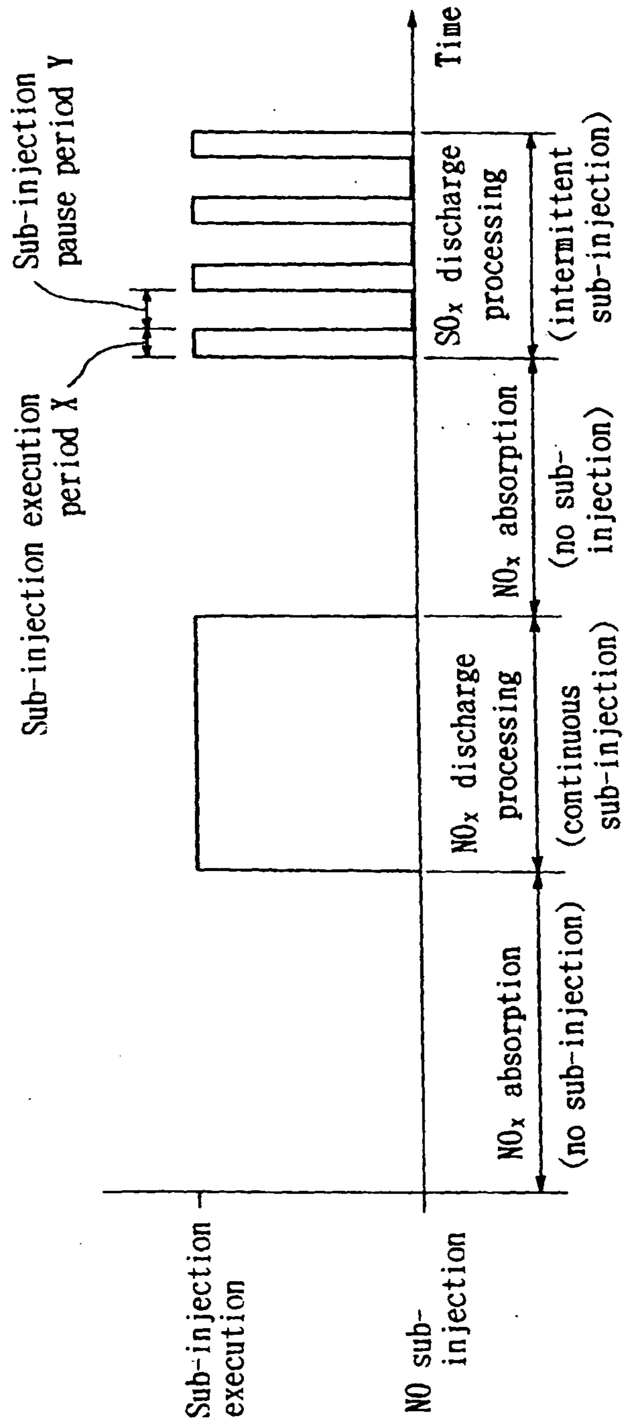

Sub-injection execution period X
Sub-injection pause period Y
Time
Sub-injection execution
NO sub-injection
NO_x absorption
(no sub-injection)
NO_x discharge processing
(continuous sub-injection)
NO_x absorption
(no sub-injection)
SO_x discharge processing
(intermittent sub-injection)

FIG.16

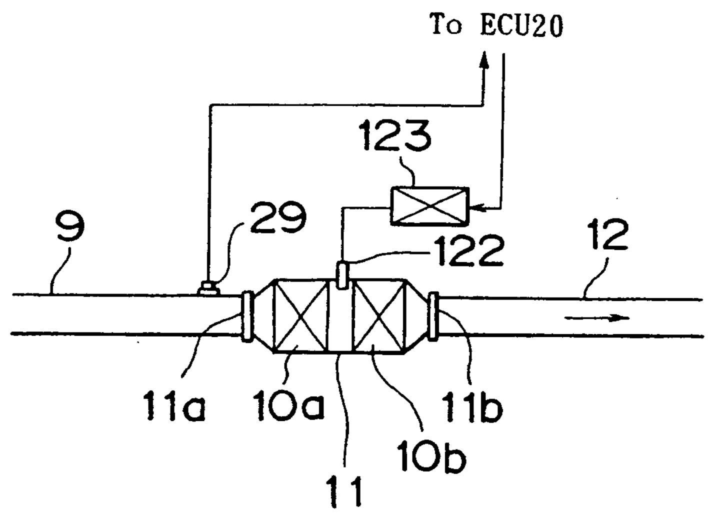

To ECU20
123
9
29
122
12
11a
10a
11b
10b
11

FIG.17

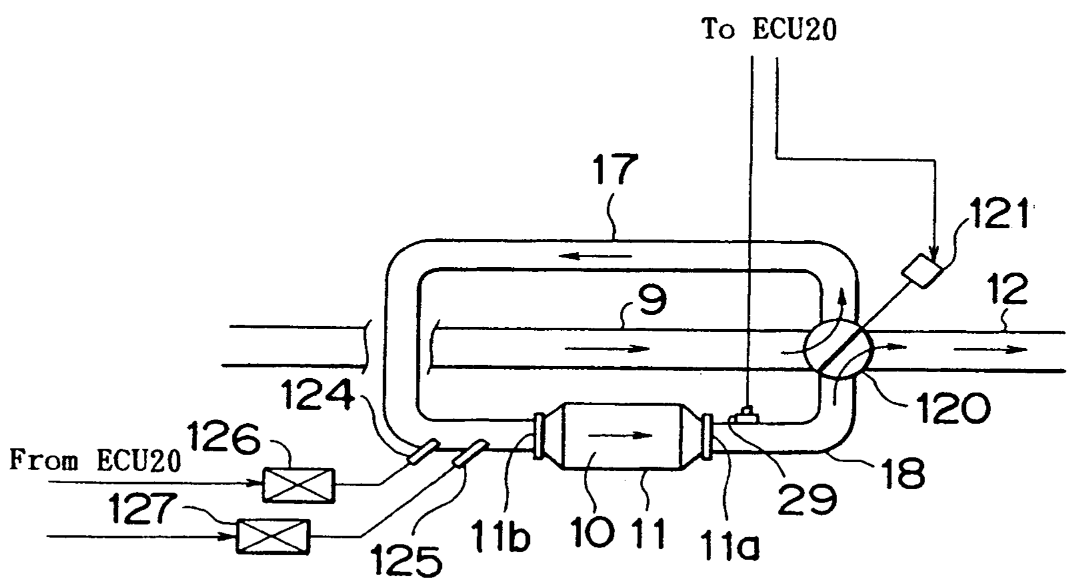

To ECU20
17
121
12
9
124
120
From ECU20
126
18
127
29
125
11b
10
11
11a

FIG.18

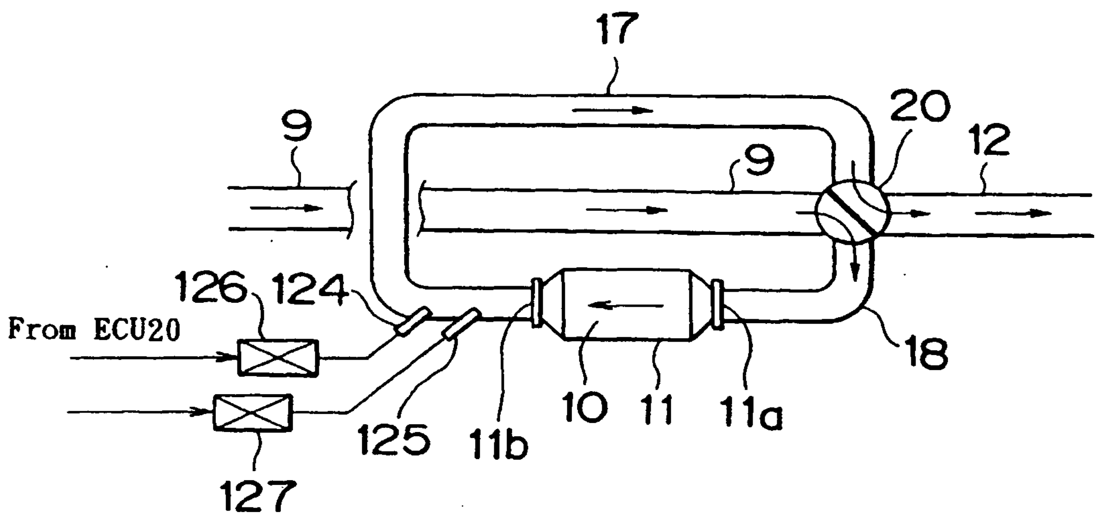

17
9
9
20
12
126
124
From ECU20
125
11b
10
11
11a
18
127

FIG.19

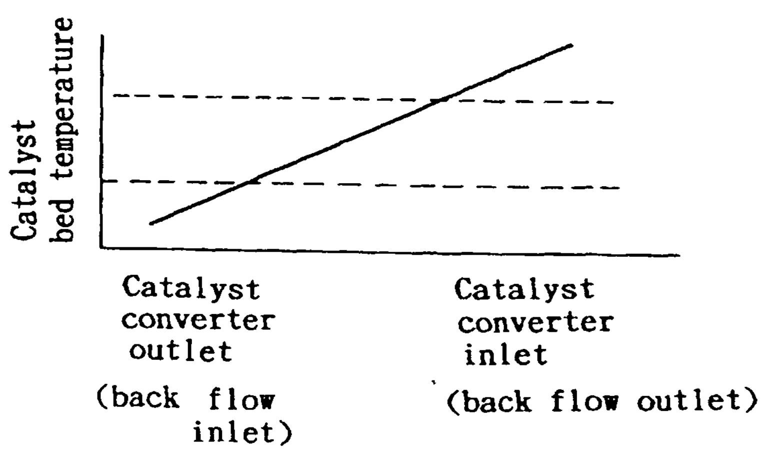

Catalyst bed temperature
Catalyst converter outlet
(back flow inlet)
Catalyst converter inlet
(back flow outlet)

FIG. 20

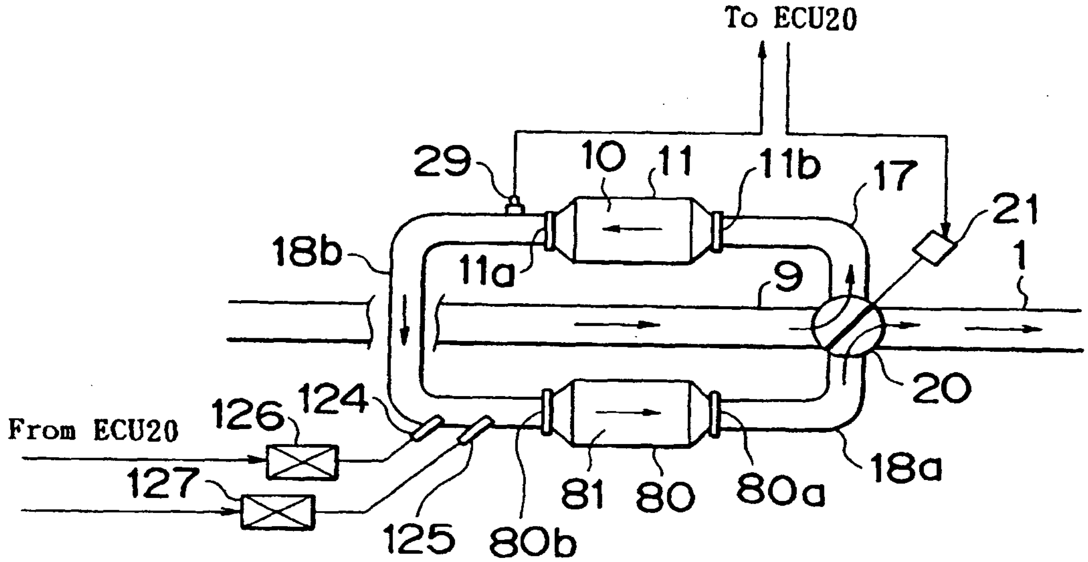

To ECU20
29
10
11
11b
17
21
18b
11a
9
1
20
From ECU20
126
124
127
125
80b
81
80
80a
18a

FIG. 21

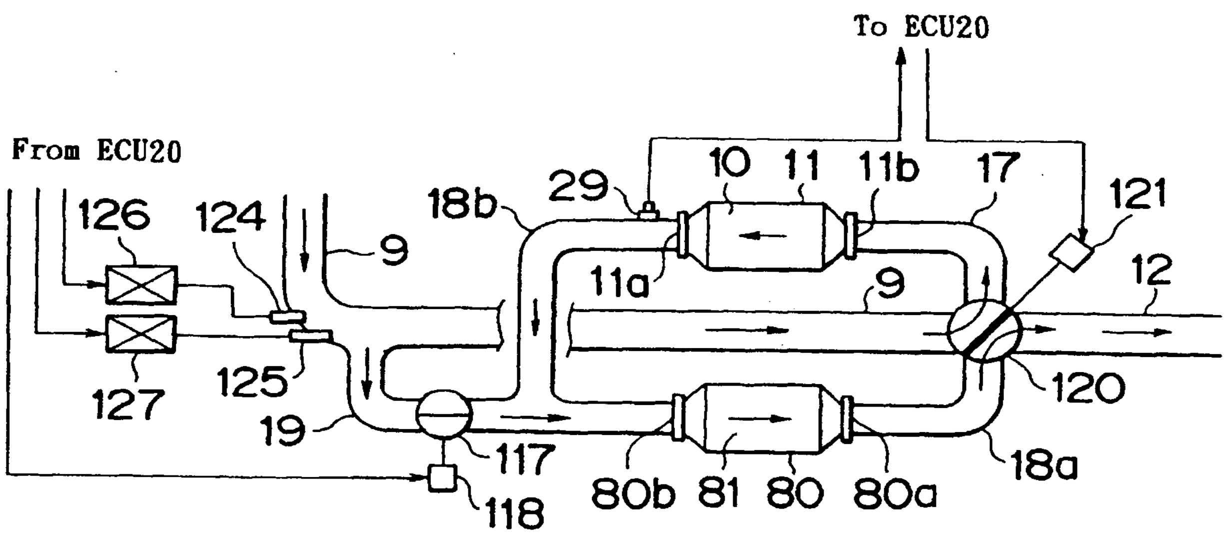
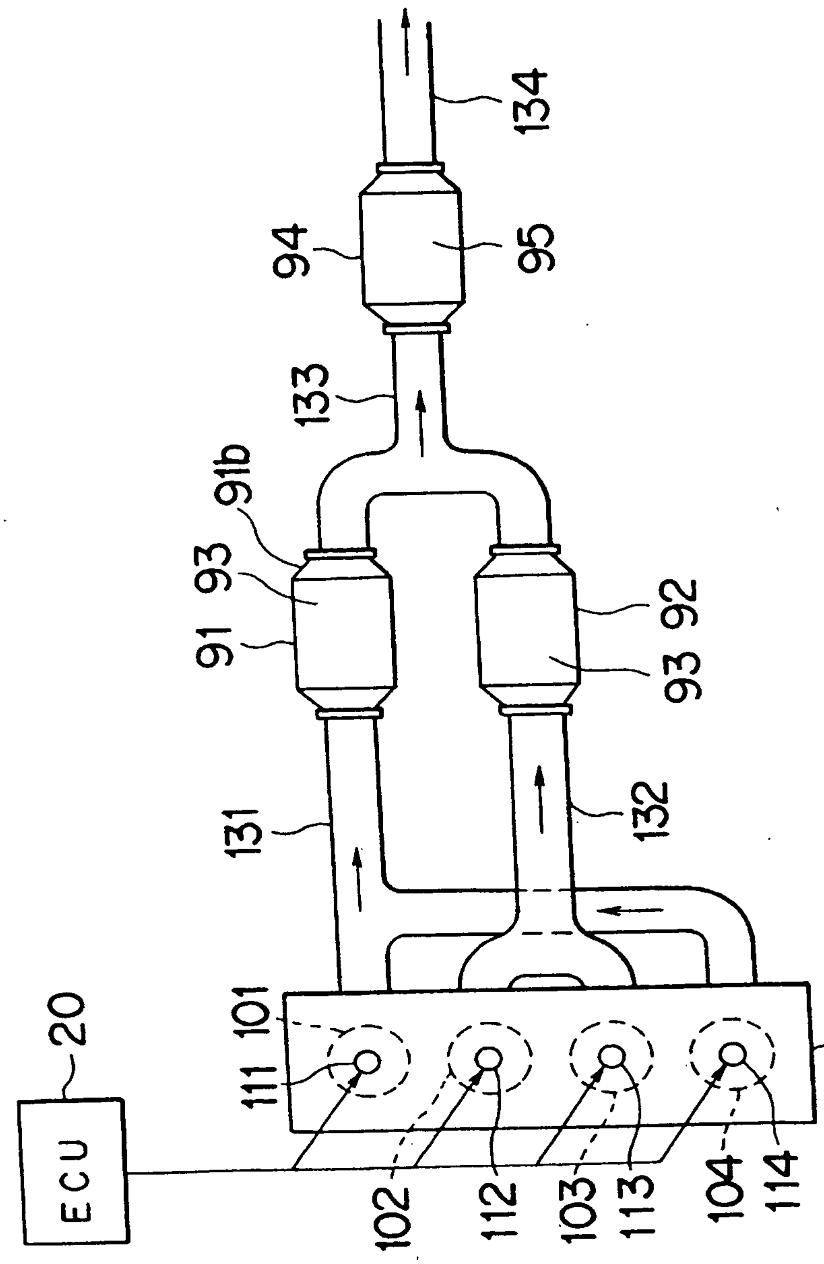

To ECU20
From ECU20
126
124
9
18b
29
10
11
11b
17
121
12
11a
9
127
125
19
117
118
80b
81
80
80a
120
18a

FIG.22



ECU
20
100
101
111
102
112
103
113
104
114
131
132
133
134
91
93
91b
92
93
94
95